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SUSTAINABLE, CIRCULAR AND INNOVATIVE VALUE CHAINS USING GROWING SUBSTRATA ALTERNATIVE TO PEAT FOR THE CULTIVATION OF NUTRACEUTICAL SPECIES

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The modern agricultural system is wasteful, with Europe generating some 700 million tonnes of agricultural and food waste each year. In the context of the agri-food chain, the 'circular economy' aims to reduce waste while also making best use of the 'wastes' produced by using economically viable processes and procedures to increase their value. In this paper we will try to frame the key issues associated with food waste into the emerging bioeconomy and circular-economic mode, suggesting that these three concepts are intertwined, and considering them unitarily might provide win-win solutions that minimize wastage, promote income growth and job creation, and prompt sustainable local development. In terms of performance and economic considerations, peat is in many ways an ideal constituent of soilless growing media. Peat has become the material of choice throughout plant production systems from propagation to saleable 'finished plant' material. However, the extraction of peat has well documented negative impacts on the environment; arguably the most important of these is the release of stable, sequestered carbon into the active carbon cycle, thereby exacerbating climate change. During the last 20 years, peat extraction has come under increasing scrutiny throughout Europe and particularly in the UK. This has generated an abundance of studies examining a diverse range of alternative materials (as compost, vermicompost, digestate, biochar). In the selection of new materials, environmental considerations have become as important as performance and economic cost. In this context there has been a justifiable emphasis on organic materials derived from agricultural, industrial and municipal waste streams. For future urban sustainability it is necessary to develop integrated processes, which can be part of a circular bio-economy. However the challenge still remains of simultaneously recycling the nutrients from the waste. The greenhouse horticulture applied to nutraceutical species is the ideal sector for improving the conversion rate of organic waste into food and health friendly products. On farm composting/vermicomposting/pyrolysis/anaerobic digestion and the use of the end-product to the partial substitution of peat in nursery activity allows reducing the environmental and economic costs in the production of potted plants.

Keywords: *Biochar, circular economy, compost, digestate, nutraceutical species, vermicompost.*

INTRODUCTION

The world is facing the depletion of natural resources due to their unsustainable use, increased global competiveness, increasing population and other environmental and economic challenges (Imbert, 2017). Under the European 2020 growth strategy launched in 2010, Europe has set itself the goal of shifting from linear to circular models of production and consumption. In this context, food waste management poses a great challenge. Climate change, especially its consequences on several developing countries, together with the growing population trends expected over the coming years, make food production a crucial issue (Imbert, 2017). Sustainable development has gained an increasingly central role in the global agenda and is now based on a circular economy model. The circular economy is grounded on resource efficiency, waste reduction, recycle and valorisation. "Food waste is a key area in the circular economy" (Comparetti et al., 2012, 2013a, 2013b, 2014, 2015, 2017; EC, 2017), and is considered as an underutilised resource that can be brought into use. The circular economy creates more employment with fewer resources (Mitchell and James, 2015). The bioeconomy is among the sectors most strongly linked to the circular economy. It includes a variety of production activities such as agriculture, forestry, fisheries and aquaculture, food, and pulp and paper production, parts of the chemical, biotechnological and energy industries, and manufacturing of bio-based textiles (Ronzon et al., 2015). Sustainability assessment needs to be further investigated through Life Cycle Assessment (LCA), complemented by Life Cycle Costing (LCC), and Social Life Assessment (S-LCA) since also economic and social aspects should be taken into consideration (Imbert, 2017). Reuse is another waste management strategy for waste that cannot be recycled and helps reduce the amount for disposal (Shekdar, 2009). Examples of reuse of organic solid waste are composting and vermicomposting processes. Composting is a biological decomposition of organic waste under either aerobic or anaerobic conditions. Similarly, vermicomposting is also a biological decomposition process of organic waste but with an addition of earthworms to speed up the biodegradation process. The composts and vermicomposts produced from organic waste can be reused as nutrient-rich organic fertilizers or for land application (Wu et al., 2014). These two processes are also highly favoured to manage solid waste owing to the high percentage of organic waste in the waste composition. Moreover, lesser costs are incurred in both composting and vermicomposting process, making them a good option to be applied in developing countries. These biological decomposition processes can be considered as a sustainable waste management strategy, which is in line with the zero waste concept. In a zero waste system, the resource flow is circular whereby the resources are conserved and recovered for reuse purposes in similar or other processes. In other words, composting and vermicomposting could be the most promising option for organic waste management, especially in lower income countries, because they incur lower cost and have lesser impact on the environment. Mechanisms of both composting and vermicomposting processes in producing organic fertilizer from the waste show that they are meeting the cleaner production concept.

SOILLESS PLANT CULTIVATION SYSTEMS

Soilless plant culture is any method of growing plants without the use of soil as a rooting medium (Savvas et al., 2013). This relatively simple definition encompasses a diverse range of plant growth systems which generally involves containerisation of plant roots within a porous rooting medium known as a 'substrate' or 'growing medium'. Compared with soil-based cultivation, soilless production can be more cost-effective (Grafiadellis et al., 2000), producing higher yields and prompter harvests from smaller areas of land (Raviv and Lieth, 2008; Nejad and Ismaili, 2014). Soilless systems also have generally higher water and nutrient use efficiencies (Savvas, 2002). The definition of an 'effective growing medium' is context specific. However, there are some general considerations that apply to all soilless growing media. As well as an appropriate physical structure, a growing medium must provide a suitable biological and chemical environment in which plant roots can effectively access nutrients. It also needs to meet the practical and economic requirements of the grower; in short it must be affordable, easy to obtain and manageable. In terms of performance and economic considerations, peat is in many ways an ideal constituent of soilless growing media (Barrett et al., 2016). It is low in plant nutrients but able to adsorb and release them when added as fertilizer (Barrett et al., 2016). Widespread reserves of peat exist in the Northern hemisphere, making it a readily available and relatively cheap resource (Maher et al., 2008). During the last 20 years, peat extraction has come under increasing scrutiny throughout Europe and particularly in the UK (Carlile and Coules, 2013; Siegle, 2014; Alexander et al., 2008; Alexander and Bragg, 2014). This has generated an abundance of studies examining a diverse range of alternative materials (Raviv et al., 2002; Bragg and Brough, 2014).

1. **Peat .**The term "peat" encompasses many different types of plant material that have been partially decomposed under anaerobic, water logged conditions. While not without some problems such as low rewetting capacity (Michel, 2010), peats generally tend to possess excellent physical, chemical and biological properties for plant growth (Schmilewski, 2008a; Krucker et al., 2010). These properties can vary widely according to conditions under which the peat is produced (Bragg, 1990; Michel, 2010). For instance, younger or less decomposed peats tend to have a higher water holding capacity than older more decomposed deposits (Maher and Prasad, 2004; Schmilewski, 2008a). Crucially, this inherent variability provides a flexible material which can be used across a wide range of horticultural sectors. In terms of its economic value, demand for peat arises from a number of industries additional to horticulture. For instance, in the EU around 1750 km^2 of peat lands are annually used for the generation of energy (WEC, 2013). Peat is also used within the agricultural industry as a soil improver and animal feed additive (Trckova et al., 2005). In terms of availability, it is estimated that peat lands cover 4 million km^2 globally (Joosten and Clarke, 2002). Traditionally, this widespread abundance has made it a relatively low cost material for use in growing media. Peat also requires relatively little treatment or few additional inputs to deliver an effective performance; thereby minimising secondary processing costs. These factors, combined with its low bulk density (which makes it light and relatively cost effective to transport), mean that peat is an economically effective component of soilless growing media. Over the last 50 years it has become an extremely well understood, reliable and consistent option for many growers. These benefits, however, present real challenges to finding comparable replacements; few of the more environmentally sustainable materials considered to date perform on a par with peat or are available in such abundance (Barrett et al., 2016).
2. **Transformed waste stream materials.** Whilst the reuse of organic wastes in soilless growing media is desirable, most industrial, agricultural and municipal waste streams are highly heterogeneous and subjected to varying levels of undesirable contamination. Secondary processing, which leads to the actual transformation of the chemical and/or physical structure of the product, is often necessary before wastes can become useful growing medium components. Transformative processes include composting (Raviv, 2013), vermicomposting (Manhand Wang, 2014), pyrolysis (Rulkens, 2008) and heat/pressure treatments (e.g. wood fibre). When any waste stream material is considered for inclusion in growing media, the cost of secondary processing needs to be assessed against the benefits of its use. Organic wastes such as sewage sludge and animal manures are often considered because they commonly contain useful concentrations of plant macronutrients (e.g. nitrogen or phosphorus) (Comparetti et al., 2012, 2013a, 2013b, 2014, 2015, 2017). For instance, municipal sewage sludge has been investigated quite extensively as a growing medium component. Its disposal represents a major challenge for urban

areas (Yachigo and Sato, 2013). Researchers have grown plants successfully in growing media containing up to 50 % composted sewage sludge (Perez-Murcia et al., 2006) and demonstrated that it can provide advantages such as increased nutrient provision (Perez-Murcia et al., 2006; Ostos et al., 2008; Topcuoglu, 2011), improved plant water availability (Kukal and Saha, 2012) and disease suppression (Cotxarrera et al., 2002). Biochars derived from a range of feedstock materials have been investigated extensively in soil-based cultivation systems (Lehmann et al., 2011; Spokas et al., 2012), but little information is available on how these might perform as, or part of, soilless growing media.

3. Methods food waste composting and its use as a peat replacement. Sphagnum peat has long been used as a growing media in horticulture and market gardening due to its high physical and chemical stability, and low degradation rate (Garcia-Gomez et al., 2002). However, peat is a finite resource, and as demand has increased in recent years prices have also risen (Herrera et al., 2008). These economic factors, combined with the negative environmental impact of peat extraction, have promoted the utilisation of alternative materials as plant growth substrates in recent years (Benito et al., 2005). Composted organic wastes are increasingly being used as a substitute for, or in combination with traditional peat, and developing such inexpensive alternatives to peat-based substrates is a priority for the agricultural industry. The use of composted organic wastes in soilless growing media has been increasing globally over the last 40 years (Rainbow, 2009; Farrell and Jones, 2010; Raviv, 2013). As a result, numerous composted organic materials derived both from plant and animal wastes can be used in soilless growing media. Composting is an aerobic process, during which a mixture of organic substrates is degraded by several microbial communities, representing a potential alternative to peat (Boldrin et al., 2009). The possibility to replace peat with an alternative substrate for nursery olive production could therefore lead to a substantial economic and environmental benefit. In 2010, a study has been initiated to assess the feasibility of a circular chain system aiming to utilize green wastes from nursery activities (mowing and pruning) to produce 'on farm' green compost and to evaluate its beneficial effect for commercial plants growth and production. This approach is the basis of the concept of the 'circular economy', which keeps the added value in products for as long as possible and eliminates waste (UE, 2014). Moving towards a more circular economy is essential to deliver the resource efficiency agenda established under the Europe 2020 Strategy for smart, sustainable and inclusive growth (Aleandri et al., 2015).

4. Digestate. Roughly one third (approximately 1.3 billion tons) of the food production in the world for human consumption gets lost or wasted (Gustavsson et al., 2011). This accounts for 6-10 % of human-generated greenhouse gas emissions (Vermeulen et al., 2012). In Europe and North America alone 95-115 kg of food per person each year (Gustavsson et al., 2011) are wasted. Aside from avoidance measures for organic waste generation anaerobic digestion is a favorable way of utilizing organic waste including food waste (Comparetti et al., 2012, 2013a, 2013b, 2014, 2015, 2017). This treatment reduces CO_2 emissions from composting or landfills and the biogas can be used for fossil fuel substitution (Appels et al., 2011; Mata-Alvarez et al., 2000). For future urban sustainability it is necessary to develop integrated processes, which can be part of a circular bio-economy. It has been proven in projects worldwide that we can generate energy from waste (Tuck et al., 2012). Fresh and untreated digestate is anaerobic liquid slurry containing plant toxic substances, a very high Electrical Conductivity (EC) and Chemical Oxygen Demand (COD). Garden waste compost may provide the necessary structure for a plant growth medium, as well as necessary nutrients in the first stage of cultivation (Hernández et al., 2016). Subsequently, digestate could provide the additional demand of nutrients in the later stages of cultivation. Thus, digestate could be a perfect complement for garden waste compost but its properties would have to be modified (Stoknes et al., 2016). Compared with chemical fertiliser, digested food waste fertiliser ought to have several environmental advantages, as high quality energy is gained in the production process and the nutrients are preserved within the effluent, i.e. the digestate. On the other hand, production of chemical fertiliser is energy intensive, contributing to indirect energy use in agriculture (Ahlgren, 2009) and fixes nitrogen from the atmosphere, thus increasing the amount of nitrogen in the biosphere. Use of digestate also contributes to carbon sequestration, as digestate organics are incorporated into the soil. However, the digestate has usually unbalanced nutrient ratios for plant growth (Camilleri-Rumbau et al., 2014). Produced fertilisers can be designed to match the crop nutrient requirements and to achieve better control of the nutrient contents of the applied fertiliser to reduce the nutrient run-off and leaching. These products could be also used to supplement the raw digestate fertilisation by replacing mineral fertilisers.

5. Biochar. With the increase of urban green space, the quantity of "green waste" has greatly increased elsewhere. Disposing of this green waste is an increasing problem, and its recycling is receiving substantial attention worldwide. Composting is one attractive option for the treatment of green wastes (Unmar and Mohee, 2008; Boldrin and Christensen, 2010), however, the long compost cycle and unstable product quality were the bottlenecks of composting. An alternative to composting is the production of biochar via carbonisation (Comparetti et al., 2011). In this process, the green waste is subjected to pyrolysis, i.e., it is heated to high temperatures in the absence of oxygen (Comparetti et al., 2011; Martinez, 2006). Growing media or substrates include all materials that can be used to grow plants with interesting uses, including greenhouse cultivation, containerized ornamental plant production, urban agriculture or green roof (Cao et al., 2014). A number of studies have shown that several organic residues such as urban solid wastes, plant wastes, sewage sludges, paper wastes, spent mushroom, coconut coir and even green wastes, after proper composting, can be used with variable results as growth media as a replacement for peat (Abad et al., 2002; Chong, 2005; Garcia-Gomez et al., 2002; Maheret al., 2007; Méndez et al., 2011; Ostos et al., 2008). Biochar is a solid carbon-rich material obtained by pyrolysis of biomass that has attracted widespread attention as soil amendment (Enders et al., 2012; Lehmann and Joseph, 2009) and, only in recent years, as growing media component (Dumroese et al.,2011; Méndez et al., 2015; Vaughn et al., 2015a,b; Zhang et al.,2014). Vaughn et al. (2015a) studied the use of biochar from several feedstocks as replacements for inorganic components such as vermiculite and perlite and digestate to replace components such as peat. Vaughn et al. (2015a) found that biochar can substitute peat at levels lower than 15 % (v/v).

6. Vermicompost. The EU accounts for almost half of the world's production of ornamental plants, which is mostly carried out in containers. The production value of this sector is estimated at 6379 million, Germany, France, U.K. and the Netherlands being the main producer countries. Increasingly, horticultural seedlings are also produced in containers due to market demands and the many production advantages, including greater production per surface unit, faster plant growth and higher plant quality. The search for alternative substrates is crucial. Compost, as a product of thermophilic processes of organic waste degradation, and vermicompost, as a mesophilic biodegradation product resulting from interactions between earthworms and microorganisms, are both humus-like materials that could act as suitable substitutes of peat (Arancon et al., 2004). Generally after vermicomposting the organic material is reduced to a more uniform size, which gives the final substrate a characteristic earthy appearance while the material from composting normally has a more heterogeneous appearance (Tiquia, 2010). Lazcano et al. (2009) consider that the biological properties of compost and vermicompost could elicit quite different effects in plant growth and morphology. Many studies have attempted to assess the potential of different organic wastes as growing media (Zheljazkov et al.,2009). Some of them only afford good results when they are properly composted: biosolids, sewage sludge, green wastes, pruning residues, olive-mill wastes, etc. (Zaller, 2007). Many kinds of residues, including poultry manure, sewage sludge, cattle manure, spent mushroom substrate, grape marc, olive mill waste, and even sugarcane bagasse, have long been considered to have low value and have usually been discarded. Safe and environmentally friendly methods of disposing and using green waste are needed. Vermicomposting is a way to treat solid organic waste. Vermicomposting involves the bio-oxidation and stabilization of organic material under aerobic and mesophilic conditions through the combined action of earthworms and microorganisms (Hait and Tare, 2011). Therefore, suitable organic waste or feedstock for earthworms is crucial to ensure a successful and efficient vermicomposting process (Yadav and Garg, 2011). Earthworms can consume most organic materials that have pH in the range from 5 to 8, moisture content between 40 and 55 % and initial C/N ratio around 30.

NUTRACEUTICAL SPECIES

There is a growing interest in herbs, spices, nutraceuticals, and medicinal plants worldwide. These species are used for food, flavourings, cosmetics, and for medicinal purposes. However, there is very little activity underway to improve the genetics and breeding of these crops. Much of the industry relies on "wild" plants (i.e. not genetically improved/enhanced); therefore, the potential for variability in crop performance and active ingredients is high, presenting significant challenges for the industry (Ferrie, 2006). Dr. Stephen L. DeFelice, M.D is credited for first using the term ''nutraceutical'', derived from the words ''nutrition'' and ''pharmaceutical''. In 1989, he stated: ''a nutraceutical is any substance that is a food or a part of a food and provides medical or health benefits, including the prevention and treatment of disease. Such products may range from isolated nutrients, dietary supplements and specific diets to genetically engineered designer foods, herbal products, and processed foods such as cereals, soups, and beverages''. The substance component includes plant, plant material, alga, bacterium, fungus, or non-human animal material. Other acceptable substances include extracts, isolates, vitamins, amino acids, essential fatty acids, and minerals (Ferrie, 2006). The European Union describes their products as either food (ordinary food, dietetic food or food supplements) or medicinal products (homeopathic medicine and traditional herbal medicines). Natural health products would be considered food supplements (e.g. vitamin supplements and herbal supplements), homeopathic medicines, traditional herbal medicines, or dietetic foods. The European Union is also considering legislation to allow nutrition and health claims for functional foods (Ferrie, 2006). The plant natural products industry is a multi- billion dollar industry worldwide. There is also a lot of interest in the use of natural products rather than conventional drugs for treating medical conditions. Market potential and interest for plant natural health products is huge, resulting in increasing demands for raw plant material. Much of the industry still relies on the harvest of ''wild'' plants. More research is also required on determining what the beneficial active ingredients are in the medicinal plants (Harborne and Baxter 2001). In Sicily, species such as *Origanum vulgare, Lavandula angustifolia, Salvia officinalis, Rosmarinus officinalis* and other similar aromatic plants could be used for nutraceutical purposes.

CONCLUSIONS AND DISCUSSION

Our current food production and consumption habits are unsustainable. Food production generates various environmental impacts, such as eutrophication and increased CO_2 emissions (Baroni et al., 2006; Bennett et al., 2001; Tilman et al., 2001). As per different estimates, approximately 30-50 % of food intended for human consumption is wasted at different stages of the food system (Gustavsson et al, 2011; Stuart, 2009). Current inefficiency in the food economy means we lose productivity, energy, and natural resources, and also bear the costs of throwing food away. More pollution and greenhouse gases are also created as a result of these processes. Circular economy offers tools to enhance and optimize for sustainability within the food system. Circular economy means reuse, repair, refurbishing, and recycling of the existing materials and products; what was earlier considered to be waste becomes a resource. Our current economic system uses the linear economic model "take-produce-consume-discard", which assumes that economic growth can be based on the abundance of resources and unlimited waste disposal. Circular economy regarding the food system implies reducing the amount of waste generated in the food system, reuse of food, utilization of by-products and food waste, nutrient recycling, and changes in diet toward more diverse and more efficient food patterns. The concept of circular economy is linked to the context of a circular food system. Potential solutions and policy recommendations analysed through a lens of transition theory are presented in order to assist the transition towards a circular food system with experiments offered by circular economy into mainstream practice (Jurgilevich et al., 2016). On farm composting/vermicomposting/pyrolysis/anaerobic digestion and the use of the end-product to the partial substitution of peat in nursery activity allows reducing the environmental and economic costs in the production of potted plants. The production system of the "on farm" compost/vermicompost/biochar/digestate can be considered as a model replicable in different nurseries and environments. However, the compost/vermicompost/biochar/digestate composition may vary after each production cycle, thus requiring basic characterization for its correct use as a component of the substrate (Aleandri et al., 2015). Continuing population growth and increasing consumption are driving global food demand, with agricultural activity expanding to keep pace. The modern agricultural system is wasteful, with Europe generating some 700 million tonnes of agricultural and food waste each year. In the context of the agri-food chain, the 'circular economy' aims to reduce waste while also making best use of the 'wastes' produced by using economically viable processes and procedures to increase their value.

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